Basin Acoustic Seamount Scattering Experiment (BASSEX) Data Analysis and Modeling

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Award Number: N00014-05-C-0077

LONG-TERM GOALS

In this program we are focusing on the science issues associated with long range ocean acoustic propagation in range-dependent environments. The primary goal is to understand the physics of the acoustic propagation in complex environments. Three specific propagation regimes are the focus of this work: 1.) seamount scattering, 2.) open ocean propagation and 3.) downslope propagation and subsequent deep water propagation. The long-term goal is understand scattering off of seamounts and island slopes and to develop algorithms for modeling the acoustic field in these severely range dependent (and azimuthally anisotropic) environments.

In the 2004 BASSEX experiment, with Chief Scientist Professor Arthur Baggeroer (MIT) and Co-Chief Scientist Dr. Kevin Heaney (OASIS), several specific areas of acoustic propagation where addressed. During the test acoustic transmissions from sources used in the SPICEX and LOAPEX experiments (PI: Dr. Peter Worcester, SIO and Dr. Jim Mercer, APL-UW), were recorded in the central Pacific using the Office of Naval Research – Five Octave Research Array. The follow on to the NPAL 2004 test is a year-long experiment planned for 2009-2010 in the Philippine Sea. The long term goals of OASIS participation are deep water propagation (bottom interaction, internal wave scattering) and signal coherence.

OBJECTIVES

The primary objective of this work is to measure aspects of acoustic propagation that we do not currently understand well (backscattering, effects of bottom roughness, propagation over basalt, 3D propagation, refraction and healing behind a sea-mount), to develop physical intuition from the data and formulate a numerical and theoretical approach to model such phenomena. The objective for this year’s effort has been to perform preliminary data analysis and to develop an understanding, through data-model comparisons, of where our physical intuition and understanding is lacking.

APPROACH

Our proposed technical approach is a multi-stage approach to signal processing of the measured data and comparison with acoustic simulations. The first step is to apply beamforming and matched filtering to all of the data. This pass was done to determine a set of receptions that contain interesting physical phenomenon for further study. Once these sets are determined, plane wave and parabolic equation (PE) modeling of the geometry associated with these receptions is performed and a detailed comparison of the prediction (using 2D propagation) and the measurement is performed. Once this

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2007	**Annual**	**00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE
Basin Acoustic Seamount Scattering Experiment (BASSEX) Data Analysis And Modeling

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Ocean Acoustical Services and Instrumentation Services, Inc.,5 Militia Dr,Lexington,MA,02421

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**7**	

step is completed, effects of bottom roughness, shear in the sediment and 3D propagation will be studied.

WORK COMPLETED

Current acoustic modeling work consists of ray-tracing in open water and broadband Parabolic Equation modeling for downslope and seamount environments. The PE modeling is only 2D and one of the significant results to date is how poor the 2D PE does at reproducing the narrowband complexity (eigenvalue distribution) of the received signal.

Geo-acoustic inversion work has been performed for the BASSEX04 receptions that are near the NPAL Kauai source. This has led to the conclusion that the seafloor near Kauai is lossy. The challenge ahead it so determine the source of the loss mechanism. Three candidate loss mechanisms being considered are volume attenuation of soft sediments, bottom roughness (particularly of the basalt basement) and shear in the basement.

Three-dimensional propagation is evident in the Kauai portion of the BASSEX test. Horizontal refraction in a shelf-environment is to be expected, though isn't well documented. What is surprising, and not well understood, is evidence of stable 3D paths in the downslope portion of the test.

The feasibility of performing Moving Ship Tomography (MST) with towed array and fixed sources was examined. The open water portion of the BASSEX04 test was used as an initial data-set. Sound was received on the FORA array as the R/V Revelle passed between the two SLICE moorings (4 sources), which were transmitting simultaneously. The resolution of the data, in particular the ability of the array to separate receptions from each SLICE source, was very promising. It was demonstrated, numerically, that the range and depth diversity of the recordings permitted an inversion for the general range dependent ocean characteristics in the region. This result, however, was contingent on both array location knowledge and accurate receiver timing. The array localization approach for the BASSEX04 array is currently using only a simple model and has ~100m accuracy. There have also been questions raised about the accuracy of the FORA timing. These two issues severely limit the ability to perform tomographic inversions from this dataset. It is hoped that both of these technical issues can be resolved prior to the next test and MST can be accomplished with a towed array as a receiver.

RESULTS

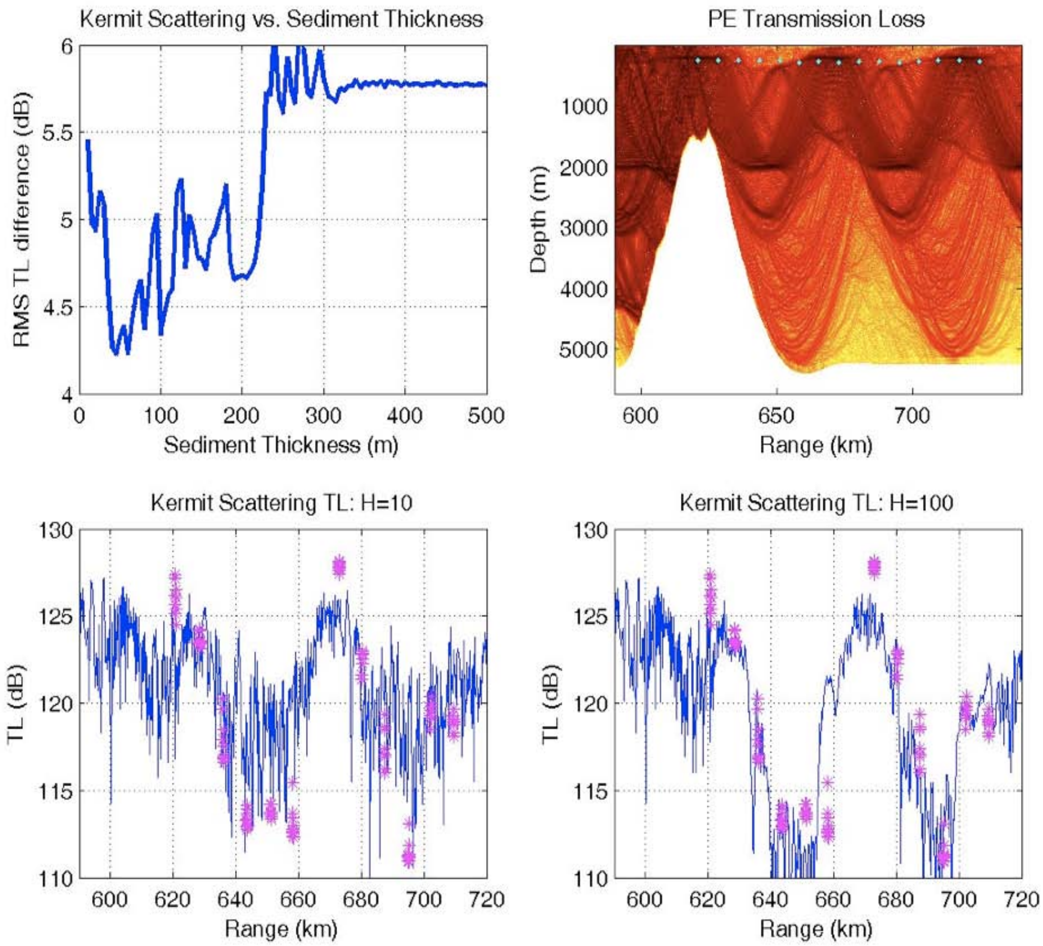

Figure 1 – Sea-mount Geo-acoustic results (upper left): cost-function-RMS TL difference (upper right): continuation PE with positions of recording, (lower left): model-data comparison with 10m sediment (lower right) model-data comparison with 100m sediment

1. Geo-acoustic inversion of deep water seamount from forward scattering

One of the issues associated with seamount scattering is the sediment thickness of open ocean seamounts. The sediment in the abyssal ocean is expected to be up to several kilometers in depth, but it is thought that currents, which increase near seamounts due to upwelling, will strip off the sediment as the seamount rises from the depths. In the BASSEX seamount scattering portion of the experiment we have several receptions recorded directly above two seamounts. Endfire measurements during tows over the sea-mount provide the opportunity for TL based geo-acoustic inversion. Results indicate that there is more than 50m of sediment. A TL based inversion, with a single homogenous sediment layer searched over sediment thickness is shown in Figure 1. The upper left panel is the cost function (RMS TL difference between model and measurements). The lowest values are optimal and show an estimated sediment thicknes from 50-120 m. The upper right is the PE solution with the field and the recording locations shown (blue *). The lower left panel shows the data (maroon *) and the predicted TL for a 10m sediment. Note the lack of a strong minimum at 640-650 km range. The seamount is at

630 km. The lower right panel shows the data/model TL for a 100m sediment and the clear shadow is observed. The approach can differentiate between thin sediments and moderate depth sediments (50-100m) but cannot determine if the sediment is beyond 100m in depth due to signal to noise issues (ownship noise in the forward endfire beam). The geo-acoustic sediment thickness is expected to be range dependent (depth dependent on the sea-mount), but this level of complexity is not included in the analysis.

2. Single Transect Moving Ship Tomography
31 receptions were taken on the BASSEX cruise as the array passed between the two SPICE arrays. The geometry of this single slice (between two sources). This single path, with all recordings taken while underway, provides a test of the single slice Moving Ship Tomography (MST) approach. In order to perform tomography with simultaneous receptions of two sources (as the moving ship passes between them), separation of the transmissions must be accomplished. Figure 2 illustrates the ability of spatial beamforming and replica correlating with nearly orthogonal matched filters to separate two simultaneous arrivals. The upper two panels are the matched filter responses for the two HLF sweeps. The overlap is clear. The lower panels show the beam matched filter responses, successfully pulling out both signals. The receptions are stable and identifiable, requirements for performing tomography. During the data analysis, it was discovered that there is a random timing error in the array. This leaves us with array element errors on the order of 100m, and timing errors on the order of 50 ms. Combined, these errors make the application of tomography to this data-set untenable. Work is underway to resolve both the timing and the array element location issues before the next test.

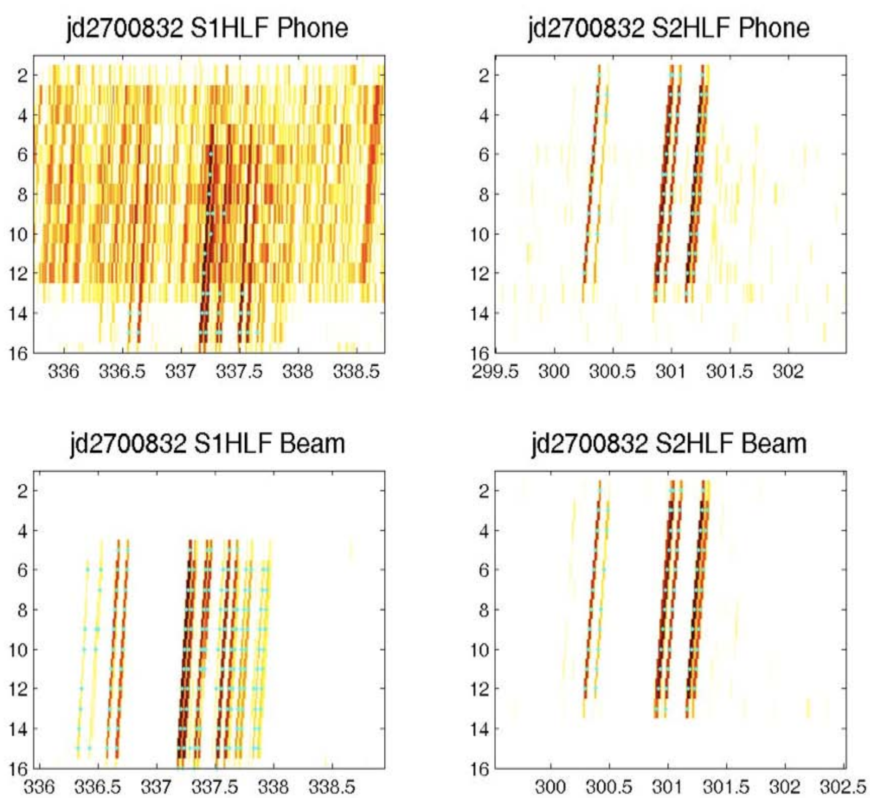

Figure 2 – Single element and beam responses for simultaneous receptions received from two sources. Note the capability of the beamformer and matched filter to separate the two signals.

3. Planning for 2009-2010 Sea Test

Effort is underway to plan the follow on sea-test. The Philippine Sea Experiment (PHIEX) will be conducted in 2009-2010, with deployments of the FORA array nominally planned for May 2009 and May 2010. The source/receiver set up will be similar to NPAL-04, except rather than single line transect (moving ship source and two source/receiver moorings), a 500 km pentagon will be in place, with the moving ship and moving towed array working a side leg of the tomography array. The issues currently being investigated by Dr. Heaney are moving ship tomography, signal coherence vs. range/frequency in deep water, deep water geo-acoustics and ambient noise directionality.

4. 3-Dimension Propagation and Environmental Uncertainty in Acoustic Propagation

During several receptions of the NPAL Kauai source, during the BASSEX experiment evidence of 3D propagation was observed. Some of these are for understandable geometries where propagation is along the coast of the island of Kauai and the sloping bathymetry is expected to lead to horizontal refraction. Others, including those shown in Figure 3, show strong 3D arrivals for paths that are down-slope into deep water. Clearly sound is "scattering" from outside of the horizontal plane, arriving at the array from a different bearing. Further analysis will include processing all of the BASSEX KNPAL receptions and performing 3D acoustic propagation modeling with a 3D PE to see if we can reproduce the observations.

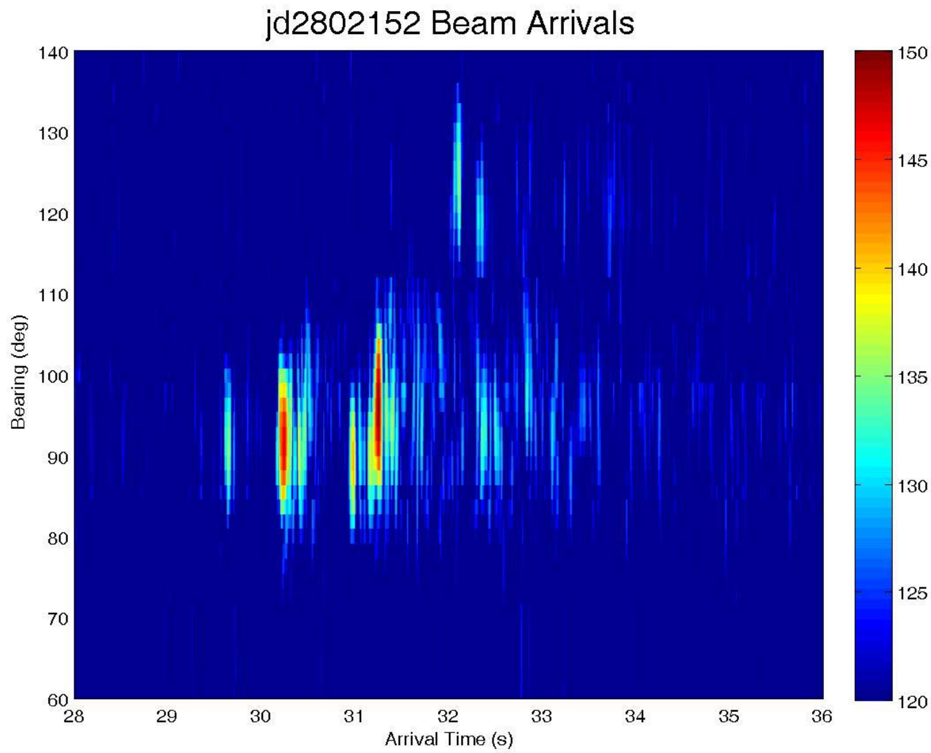

Figure 3 – Beam time series from a deep water reception. Stable, identifiable arrivals are observed on the array with an incedent angle of 130 degrees when the direct blast (including all of it's multipath) is coming in at 90.

5. Geo-acoustic inversion over range-dependent basalt
The region near Kauai has been of significant importance to the long range acoustics community because of the placement of the NPAL Kauai source. Bathymetric interaction was studied in Vera and Heaney[1], and in Heaney[2]. Prior to understanding three-dimensional propagation effects and downslope propagation evolution of the signal into deep water, an accurate geo-acoustic model must be determined. During the BASSEX sea-test at least 4 receptions were recorded within 10 km of the Kauai source primarily for the purpose of geo-acoustic inversion. Inversion results to-date indicate a thick-sediment (H>200m) of sand/silt.

This inversion is based upon a 2 parameter brute-force search of a simple time-domain cross-correlation (after searching on optimal range) of the received and PE modeled signal at for a single transmission (40 periods) extending from a range of 2-4 km. Future inversion work will be based upon striations for the frequency band 5Hz-120Hz and a matched-field based genetic algorithm inversion. To date there have been no indications that shear in the basalt is a dominant physical process – though it may turn up as an anomalous attenuation.

IMPACT/APPLICATIONS

Many sites of potential tactical naval interest exist in the world where there is strong downslope range-dependence and the presence of rough bottoms that have shear wave propagation. With a systematic approach to data analysis, data-model comparison and theoretical development it is expected that a better capability of modeling acoustic propagation in this difficult environment will be arrived at.

RELATED PROJECTS

The SPICEX and LOAPEX experiments where conducted at the same time as the BASSEX experiment, as the other two parts of the North Pacific Acoustic Laboratory (NPAL 04) sea-test. The SPICEX experiment transmitted broadband signals with a center frequency of 250 Hz from two source moorings located a distance of 500 and 1000 km away from a vertical line array mooring. The science to be investigated during this test is the scattering of acoustic energy in the mixed layer. An understanding of the combination of acoustic scattering in the mixed layer, and mixed layer oceanography is sought through this data set. The LOAPEX experiment transmitted broadband signals centered at 75Hz from ranges of 50, 250, 500, 1000, 1600, 2300, 3200 km to the same vertical line array. An understanding of the dependence upon range of the effects of internal wave scattering is sought through this data set.

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1. Vera, M., K.D. Heaney, and N. Group, *The effect of bottom interaction on transmissions from the North Pacific Acoustic Laboratory Kauai source.* Journal of the Acoustical Society of America, 2005. **117**(3): p. 1624-1634.

2. Heaney, K.D., *The Kauai Near-Source Test (KNST): modeling and measurements of downslope propagation near the NPAL Kauai source.* Journal of the Acoustical Society of America, 2005. **117**(3): p. 1635-1642.

PUBLICATIONS

3 Papers presented at ASA meeting in Hawaii related to BASSEX work.